Analysis of Permeability Coefficient on Stabilized Peat using *Bacillus Subtilis* Bacteria

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ABSTRACT

In construction sector, peat is one type of soil that is avoided because it has poor characteristics. This is because peat has very different characteristics when compared to other types of soil. Poor peat characteristics often lead to damage and construction failure of infrastructure buildings on peat. For example, large settlement values are caused by high peat compression that strongly influenced by its permeability value. The smaller the permeability value, the smaller the compression that occurs. Indonesia has the largest peatland distribution in Southeast Asia, this is a problem that must be resolved immediately. Much research has been done to improve the characteristics of peat, one of which is peat stabilization. Microbially Induced Calcite Precipitation (MICP) method using *Bacillus subtilis* was considered as an effective method in peat stabilization. This stabilization can reduce the permeability value of the peat by closing the pores in the peat. To investigate the influence of the bacteria on the peat sample, several tests was conducted including the physical property and permeability test. In this study, the addition of *Bacillus subtilis* bacteria solution can reduce the permeability value of peat from 0.001170 cm/sec to 0.000317 cm/s at the addition of 5% bacteria solution.

Keywords : Peat, Stabilization, Microbially Induced Calcite Precipitation (MICP) , *Bacillus subtilis*, Soil permeability.

1. INTRODUCTION

Peat is a type of organic soil formed from the accumulation of plant residues over thousands of years [1]. In infrastructure works, peat is a very unfavorable soil type [2]. This is due to the very different characteristics of peat when compared to other soil types. Peat has a low bearing capacity, high moisture content, volume weight or density and small pore number, low pH value making it acidic and high soil sensitivity [3], [4], [5].

Indonesia, as an archipelago, has four large islands with a peat distribution of 13.43 million hectares, making it the country with the largest peat distribution in Southeast Asia [6]. The decreasing amount of land makes development on peatlands is unavoidable. One of the methods that can be used is to improve the characteristics of the peat. Peat characteristics can be improved through a soil improvement process, such as stabilization [7]. Currently, peat stabilization using chemicals for example Portland cement, silica, lime and other chemicals needs to be avoided because they can pollute the environment [8], [9]. One type of stabilization that is considered effective and does not pollute the environment is stabilization using bacteria that produces the enzyme urease [10], [11], [12]. The stabilization process is carried out by the Microbially Induced Carbonate Precipitation (MICP) method which utilizes the metabolic process of bacteria to produce calcium carbonate or $CaCO_3$ precipitation [13]. *Bacillus subtilis* bacteria is one type of bacteria that can be used in this process [14]. Therefore, in this research, peat stabilization will be carried out using *Bacillus subtilis bacteria.*

In 2019 [15], stabilization with these bacteria was carried out and showed changes in the characteristics of organic soil with an increase in the cohesion value in the Triaxial-UU test, which increased from 0.1688 kg/cm^2 and 0.2598 kg/cm^2 to 1.3375 kg/cm^2 and 1.1625 kg/cm^2. Moreover, in 2021, research was also conducted to see the increase in CBR value of peat with stabilization using *Bacillus subtilis* bacteria and sand. In this study, no significant change was found with the addition of sand in the stabilization process. The research showed that the addition of 5% sand and 15% bacterial reagent had a CBR value of 0.9% and a free compressive strength value of 0.42 kg/cm^2 [16]. From these two studies, no analysis was conducted regarding changes in the physical properties of the peat that had been studied.

This research aims to stabilize peat with *Bacillus subtilis* bacteria with a comparison of peat permeability values. A decreasing permeability value is a sign that the sample has changed its physical properties and characteristics from the initial condition. From the results of the stabilization, an analysis will be carried out regarding the changes in the physical properties of the initial peat and the stabilized peat. Permeability is the speed of a liquid/fluid in porous media in a saturated state, while permeability in soil is defined as the speed of water to penetrate the soil in a certain period of time expressed in units of cm/second [17]. The permeability speed in soil is determined by the particle size, the ratio of voids in the soil, the absorption rate, and the constituent structure of the soil mass. The permeability value of the soil affects the construction of infrastructure built on the soil [18]. The permeability value of peat soil has a greater value when compared to other types of soil such as clay, silt, or sand [19].

2. METHODOLOGY

This research aims to analyze the changes in the physical properties of peat that has been stabilized with *Bacillus subtilis* bacteria using the MICP method by looking at the decrease in the permeability value of peat that occurs. The implementation of this research is described as follows.

2.1 Peat Sampling

Peat samples were collected in Palangkaraya City, Central Kalimantan in the form of undisturbed samples and disturbed samples. The undisturbed peat sample will be used as a comparison to the peat sample that will be stabilized with *Bacillus subtilis* bacteria. The soil sampling location is shown in Figure 1.

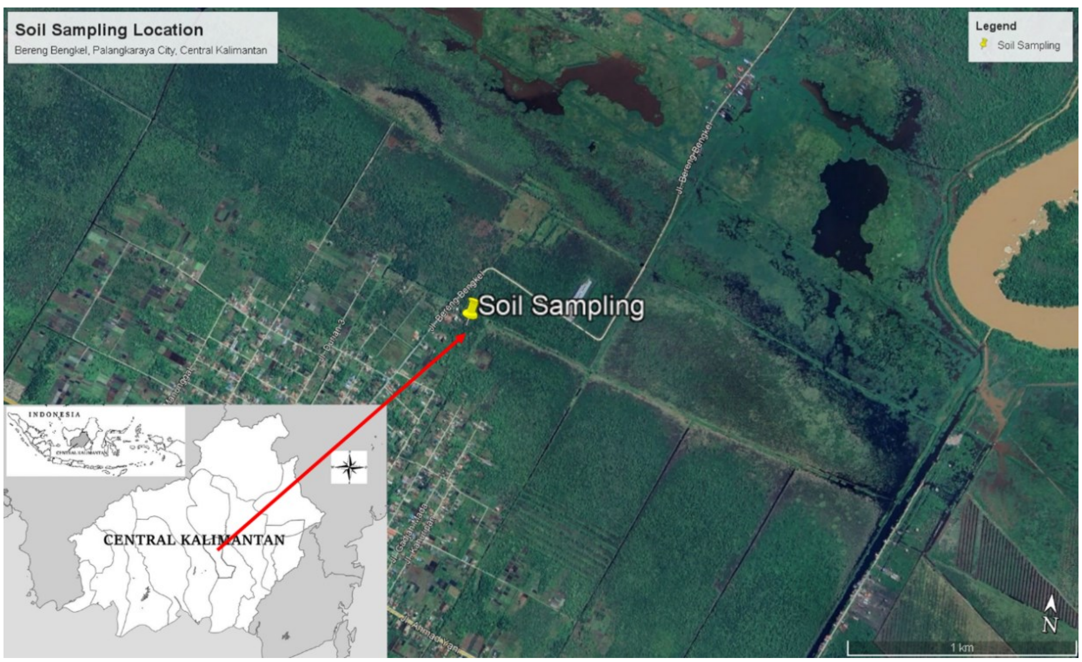

Figure 1 Soil Sampling Location in Palangkaraya, Central Kalimantan

2.2 Stabilization of Peat Samples with Bacteria

The implementation of peat stabilization with Bacillus subtilis bacteria begins by making a bacterial stabilization solution. After the solution was made, it was then mixed into the disturbed peat sample. The mixing ratios used in this study were 0% (original condition), 5%, and 10%. The ratio of bacteria solution addition was based on the weight of soil in original condition (γt). After mixing the bacteria, the peat will be curing for 28 days. The process of making the stabilization solution and mixing the stabilization solution with peat is shown in Figure 2. Figure 2a shows the preparation process of Bacillus subtilis bacteria in the form of bacterial culture followed by the preparation of bacterial stabilization solution, the results of are shown in Figure 2b. In Figure 2c, the peat samples and bacterial stabilization solution were mixed according to the predetermined variations. The calculation of the variation in the addition of the solution was carried out on the volume weight of the original condition peat (γ_t).

Permeability is the property of porous soil to be able to drain liquid seepage in the form of water that flows through soil pore cavities [20]. In permeability test, in addition to the peat sample, data related to the initial height, final height, hose area, tube surface area, tube height, and time are needed. The final height in the permeability data is obtained from the results of changes in the predetermined time [21]. Based on the test data that has been obtained, the permeability coefficient is calculated using Equation (1).

$$k = 2.303\frac{aL}{At}log\frac{h_1}{h_2} \qquad (1)$$

(a) (b) (c)

Figure 2 Process of Making Stabilization Solution and Mixing Stabilization Solution with Peat

In Equation (1) k is permeability coefficient (cm/s), a is the cross-sectional area of measuring pipe (cm^2), A is the cross-sectional area of soil sample (m² or cm²), and L is the length of soil sample (m or cm). Moreover, t refers to fluid travel time along L (s/sec), h_1 refers to the initial height (m/cm) and h_2 is the final height (m/cm).

After the peat curing time is complete, the next step is to make samples for permeability test. The permeability test will be conducted based on ASTM D5084. From each variation of peat soil sample, one test specimen was made. The test specimens that have been made are then measured and weighed as supporting data for the calculation of the permeability coefficient. The permeability test used is the falling head permeability test because this test is suitable for measuring the permeability of fine-grained soils. The tools used in this test are a vernier, scales with an accuracy of 0.01gr, PVC pipe, meter, and stopwatch. The falling head permeability test process is shown in Figure 3. Figure 3a shows the process of making permeability test samples in the form of measuring sample weight. Figure 3b is a peat sample with various variations that have been determined, which are then tested with the constant head permeability test method shown in Figure 3c.

(a) (b) (c)

Figure 3 Permeability Test

2.3 Testing the Physical Properties of Peat

Testing of the physical properties of peat was carried out on the peat in its initial condition and the stabilized peat. The test was conducted in accordance with the standards applicable to peat samples. The physical properties tests have been conducted in this research, including natural water content test (as per ASTM D 2216), specific gravity (as per ASTM D854-14), density test (following ASTM D7263), organic and ash content (in accordance with SNI 13-6793-2002), and fiber content test (based on Peat Testing Manual 1979).

2.4 Analysis of Test Results

Analysis of the test results that have been carried out includes analysis of the results of permeability test and the results of physical properties test of peat. These test results then were compared to obtain the effect of the stabilization to the peat permeability coefficient.

3 ANALYSIS AND DISCUSSION

3.1 Permeability of Peat Samples

The peat permeability test was carried out under 28 days of curing or the maximum curing time. From the results of the falling head permeability test conducted, it was shown that sample No.2, which was peat with 5% *Bacillus subtilis* bacterial solution added, had a smaller permeability rate when compared to sample No.1, which was peat in its initial condition. The peat with 5% bacterial solution had a permeability coefficient (k) of 0.00317 cm/s, which decreased by about 72.9% from the initial peat. These results show that the addition of *Bacillus subtilis* bacteria solution to the peat can close the cavities in the peat or fill the cavities so that the time to pass water becomes longer. From the permeability test, it can be concluded that the MICP process with the addition of *Bacillus subtilis* bacteria solution can reduce the permeability value of peat. The results of permeability test on peat samples are shown in Figure 4.

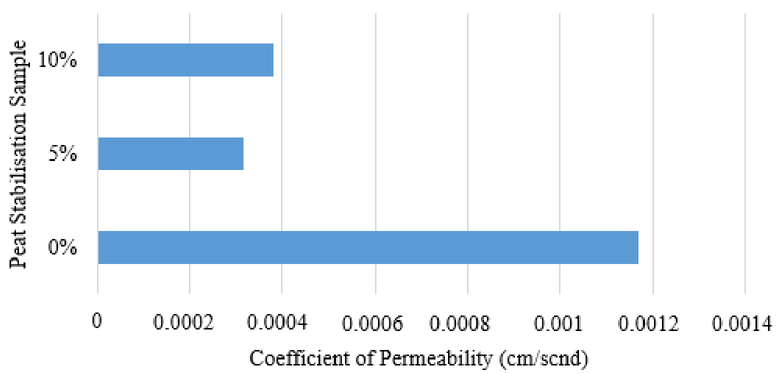

Figure 4 Permeability Test Result

Although the test results produced good values, the amount of $CaCO_3$ present in peat will tend to be less than in sandy soils [22]. This is related to the organic matter in the peat, which inhibits the entry of $CaCO_3$ and inhibits crystal growth. In several previous studies, it was mentioned that the organic content of a material, in this case peat, can prevent the precipitation of $CaCO_3$ [3].

3.2 Moisture Content of Peat Samples

One of the disadvantages of peat stabilization using the MICP process is the form of the stabilization material, which is a bacterial solution. The addition of the bacterial solution made the peat sample, which already contained a lot of water, muddier due to the additional water content in the sample. It should be noted that peat is a type of soil that contains a lot of water. From the two peat samples with the addition of *Bacillus subtilis* bacteria, it was found that the addition of 5% bacteria with a 28-day curing period can reduce the water content by 31.79%. The water content of the initial peat sample was 639.35%, which decreased to 436.106%. At 14 days, there was an increase in moisture content caused by the addition of the bacterial solution. This decrease in moisture content can occur due to bacterial activity in the peat sample which accelerates the process of decomposing the fibers in the peat. The decomposition of the fibers in the peat causes the water to evaporate more easily. The results of the water content test for all peat samples are shown in the Figure 5.

3.3 Fiber Content of Peat Samples

Peat is a type of soil that contains a lot of fiber, this is because peat is created by the accumulation of plants that have decomposed for thousands of years. According to Hartono [23] the fiber content of peat causes peat to have a low ability to withstand the load acting on it. The fiber content of peat also causes peat to contain a lot of water due to the macropores and micropores present in peat [24]. The addition of *Bacillus subtilis* bacteria in the implementation of this stabilization can make the fiber content of peat decrease. The best decrease occurred in the sample with the addition of 10% bacteria with a decrease of 76.66%. The fiber content in the initial condition was 53.23% to 12.42%. The decrease in fiber content was caused by microbiological activity that occurred due to the addition of *Bacillus subtilis* bacteria. In this study, it can be seen in Figure 6 that there was a decrease in fiber content in peat samples with 14 days and 28 days of aging. This shows that Bacillus subtilis bacteria can accelerate the decomposition process of fiber in peat.

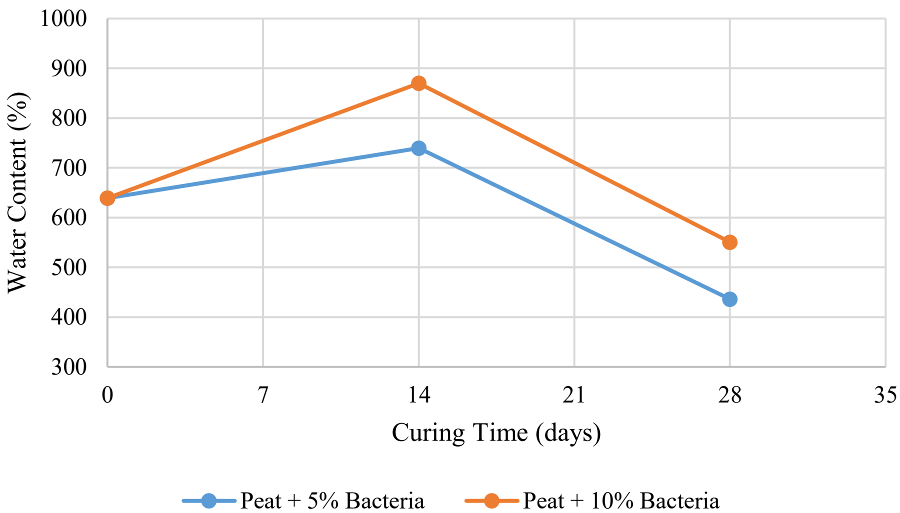

Figure 5 Water Content Test Result

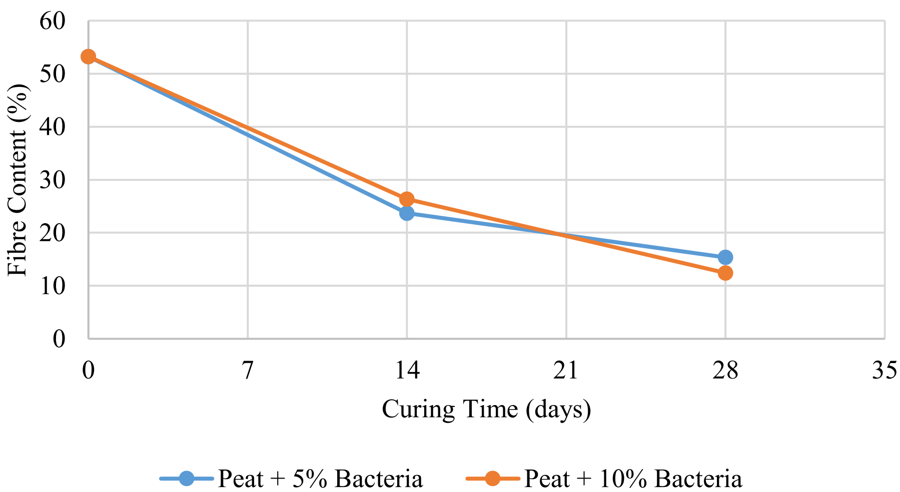

Figure 6 Fibre Content Test Result

3.4 Physical Properties of Peat in Initial Condition

Changes in peat characteristics due to the addition of *Bacillus subtilis* bacteria can be determined by comparing the physical properties of peat in its initial condition and the stabilized condition. Therefore, it is necessary to conduct preliminary test in the form of testing the index properties or physical properties of the initial condition peat samples to be stabilized. Testing the physical properties of the peat consisted of testing the moisture content, specific gravity, weight, fiber content, fiber size distribution, and peat acidity (pH). The results of the peat physical properties test are shown in Table 1.

As seen on Table 1, the peat samples tested are included in fibrous peat with a fiber content of >20% [7]. Fibrous peat is peat that has a low ability to withstand loads and has a large compression value [23]. The moisture content of the peat sample reached 639.35% with a wet volume weight of 0.98 gr/cm^3 and a dry volume weight of 0.13 gr/cm^3. This shows that the peat sample is dominated by water with a ratio of 6 times more than the soil grains. This peat sample has a fiber content of 53.23% with a predominantly coarse fiber size of 56.61% which, according to ASTM D4427-84, is included in hemic peat. In addition, the peat has an acidity level of pH

3.2. Based on the results of this description, it can be concluded that the peat sample tested is a type of fibrous peat with a high fiber content, high acidity, and moderate water absorption ability.

Table 1 Physical Properties of Peat in Initial Condition

No.	Characteristic	Unit	Value
1	Specific gravity (*Gs*)	-	1.48
2	Water Content (*wc*)	%	639.35
3	Volume Weight (γ)	gr/cm^3	0.98
4	Dry Volume Weight (γ_d)	gr/cm^3	0.13
5	Pore Number (*e*)	-	10.12
6	Acidity (pH)	-	3.2
7	Fiber Content (*Fc*)	%	53.23
	- Coarse Fiber Content	%	56.62
	- Medium Fiber Content	%	26.38
	- Fine Fiber Content	%	17.00
8	Soil Permeability	cm/s	0.00117

3.5 Physical Properties of Stabilized Peat Results

From the results of the physical properties tests, it is known that the addition of 5% bacterial solution provides good stabilization results compared to the sample with 10% bacterial solution. To determine the improvement that occurred, the physical properties of the stabilized peat samples were tested and then compared with the physical properties of the peat samples in the initial condition. The test consisted of moisture content test, specific gravity test, weight test, fiber content test, fiber size distribution test, and peat acidity (pH) test. The test results for the stabilized peat samples are shown in Table 2.

Table 2 Physical Properties of Peat After Stabilization

No.	Characteristic	Unit	Value
1	Specific gravity (*Gs*)	-	1.90
2	Water Content (*wc*)	%	436.10
3	Volume Weight (γ)	gr/cm^3	1.056
4	Dry Volume Weight (γd)	gr/cm^3	0.19
5	Pore Number (*e*)	-	8.87
6	Acidity (pH)	-	6.5
7	Fiber Content (*Fc*)	%	15.35
	- Coarse Fiber Content	%	25.68
	- Medium Fiber Content	%	30.44
	- Fine Fiber Content	%	43.87
8	Soil Permeability	cm/s	0.000317

3.6 Analysis of Peat Sample Test Results

The results of the testing of the stabilized peat samples showed characteristics in the form of better physical properties when compared to the peat samples in the initial condition. This was shown by a decrease in the moisture content of the peat from 639.35% to 436.10%, and an increase in the volume weight of the peat from 0.98 gr/cm^3 to 1.056 gr/cm^3. Peat, which is basically an organic soil, has a high acidity of pH 3.2. After stabilization, the acidity of the peat is close to neutral, pH 6.5. The fiber content of peat, which is the main element in peat, also decreased from 53.23% to 15.35%. This decrease indicates that the Bacillus subtilis bacteria used are useful in breaking down the fiber in the peat. Based on the results of this description, it can be concluded that the initial peat sample is a type of fibrous peat with high fiber content, high acidity, high organic content, and moderate water absorption capacity. After stabilization, it can be concluded that the peat changed to amorphous peat with low fiber content, neutral acidity, low organic content, and low water absorption capacity. In addition, based on the peat permeability value, it can be concluded that the stabilized peat has fewer pores when compared to the peat in the initial condition. This causes water to take longer to flow through the pores of the peat.

4 CONCLUSIONS

The large compressive value of peat leads to frequent damage and construction failures of infrastructure on peatlands. In this study, stabilization was carried out to reduce the permeability value of peat, offers an alternative solution to the specialized treatment applicable for the infrastructure works on peatlands. Based on the research and discussion carried out, it can be concluded that the stabilization that has been carried out on peat samples can change the characteristics of these samples. The permeability value of the peat in the initial condition was 0.00117 cm/s, which decreased to 0.00317 cm/s when 5% *Bacillus subtilis* bacteria solution was added. This is because during the MICP process, the calcium carbonate formed can close and fill the cavities in the peat. The filled cavities cause the peat to take longer to pass water. In addition to permeability, changes also occurred in the moisture content, specific gravity, weight, acidity, organic content, fiber content, and fiber size distribution of the stabilized peat samples when compared to the initial peat samples. Upon further investigation, changes in the characteristics of the peat can indicate changes in the strength of the peat in the form of soil bearing capacity. Therefore, research on the engineering properties of peat needs to be conducted.

The results of this study can be used as a basic reference in the implementation of peat stabilization with the MICP method using *Bacillus subtilis* bacteria. Further research on the changes in mechanical properties of stabilized peat samples can be carried out to determine changes in the strength of these samples. Further research can be carried out by increasing the variation in the ratio of bacteria solution addition. This is done to determine the optimum variation of addition for peat stabilization using bacteria.

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